Biomechanical Study of an Anthropometrically Designed Hip Protector for Older Chinese Women

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Biomechanical properties and compliance are 2 essential properties of hip protectors (HPs) that determine their clinical efficacy. This study describes the development of a HP that was anthropometrically designed according to anthropometric data from 68 older Chinese women and with attention paid to the biomechanical properties of the device. A simulated mechanical fall test using a drop weight and a force plate were set up to test the force attenuation properties of the HP. The HP attenuated up to 93% of the impact force, and the remaining force was 2 standard deviations below the mean fracture threshold of the proximal femur. The HP was effective in force attenuation, and the anthropometric data obtained provides important information for the development of HPs adapted for a Chinese population. Further study on the compliance and clinical efficacy of this HP is underway. (*Geriatr Nurs* 2008; 29:64-69)

A hip protector (HP) is an external device that provides protection from fractures to the hip due to falls.[1] An HP usually consists of a pair of hard, energy-shunting pads that cover the area around the greater trochanter and are held in place by a pair of specially designed pants. Whether HPs are effective in the prevention of hip fractures is controversial.[2-4] A recent meta-analysis of evidence from more than 9,000 subjects in 11 clinical trials showed that use of HPs reduces the incidence of hip fracture by 23%.[4] The effectiveness of HPs was more obvious among institutionalized elderly, reducing hip fractures by up to 80%.[5-8] However, another pooled analysis of 6,000 subjects from 7 clinical trials did not show any beneficial effects of HPs.[3] The majority of trials involved in this meta-analysis were conducted among community-dwelling elderly, who may be healthier and have a lower incidence of hip fracture; thus the treatment effect of HPs might not be easily detected in this population.[9-12]

Poor subject compliance is the major obstacle to the effectiveness of HP.[13] A previous study showed that all the hip fractures found in the intervention group occurred when HPs were not being used.[9] Major challenges have been identified in the use of HPs; these include complaints of bulky pads and of the devices being uncomfortable, tight, and awkward to wear.[13] In particular, devices that did not fit well or were too tight were significantly correlated with noncompliance and dropouts.[14-15] A few studies showed that HPs made of softer materials designed with sewn-in pads could encourage better compliance.[16-17] The force attenuation properties of these devices has often been questioned.[12,18] However, hip fractures seldom occur if a subject wears an HP[2-4] if it provides adequate force attenuation to reduce the impact of falls to a level below the fracture threshold of the proximal femur.[19]

Currently available HPs, which are designed for Caucasians, are not suitable for the Chinese population,[20,21] who require a different fit because of ethnic differences in anthropometry.[22] Designing an HP that fits well is crucial to enhance compliance. Furthermore, wearing tight pants in hot, humid places such as Hong Kong is also uncomfortable and challenging. Therefore, selection of fabrics with properties that disseminate heat and humidity is also crucial to design a good HP. In light of the increasing numbers of older adults with osteoporosis and subsequent hip fractures in China,[23] development of an effective HP has significant clinical implications. This study describes the development of an HP for Chinese elderly and reports the initial test on its force attenuation properties.

Methodology

Anthropometric Measurement

The study included 68 ambulatory women with mean age of 75.4 (± 6.2), recruited from an elderly hostel, who underwent anthropometric measurement to design pants made to fit the bodies of older Chinese women. The reason for including only women in the study was because women have a higher risk of hip fracture than men.[23] The measurements included waist, hip, and thigh size (circumference of first round) and vertical distances between the greater trochanter and waist, the hip and waist, and the first round (proximal thigh near to groin) and waist. Each measurement was performed 3 times with tape measures. The mean values of the 3 measurements were used for calculation. All measurements were performed by a well-trained research staff. The Clinical Research Ethics Committee of the Chinese University of Hong Kong approved this study (Ref. No.: CRE-2004.331).

Design of the Pants

Mean values of the anthropometric data were used to determine the cutting and sizes of the pants. Consultation with the Institute of Textiles and Clothing of the Hong Kong Polytechnic University were made on the selection of fabric for the pants. Knitted fabric (93% cotton, 7% Lycra) was selected because of its satisfactory and balanced properties in terms of texture, air permeability, water absorbance, strength, and dimensional stability.

Design of the Pads

Semiflexible thermal plastic, Orfit (ORFIT Industries, New York), which is an allergy-free plastic appropriate for direct application to skin,[24] was used to make the plastic shield of the pad. Low-density silicon was padded along the edge of the plastic shield (Figure 2) to provide better cushioning for the users to avoid discomfort caused by pressure from the pads.[25] The maximum width and length of the pads were 9 cm and 14 cm, respectively, which is sufficient to cover the greater trochanter of older Chinese women.[26] The maximum height of the pad was 2.5 cm, including a 1.5-cm gap between the inside of the pad and the skin, which was recommended for safety.[18]

Figure 1. Composition of the hip protector pads.

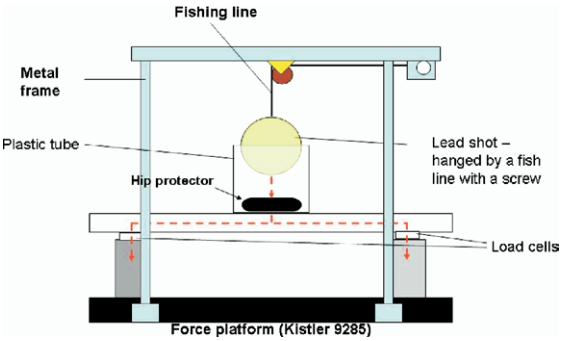

Figure 2. Mechanical test set up for the hip protector pads.

Mechanical Test of the Pads

A drop-weight test consisting of a force platform (Kistler 9285, Kistler Instrument, New York) and a 7-kg lead shot was set up to test the force attenuation properties of the pads (Figure 1). The lead shot was performed by a fishing line from a height of 0.15 m to provide an impact of approximately 7,000 N and 0.25 m to provide 10,000 N, which respectively simulate the amount of impact of a fall under a low-impact condition with the muscle in a relaxed state and a high-impact condition with the muscle in an active state.[18]

The sampling rate of the force platform was set to 2000 Hz so that it would have adequate sensitivity to record the impact force with a duration of impact estimated to be in milliseconds.[27] A lead shot was used because a sphere would provide the same impact even if the orientation of the lead shot was different at the moment of release. This was important to ensure the test-retest reliability and minimize systemic error. Five identical samples were tested in each of the impact conditions. Five successive drops were performed to ascertain the variation of force attenuation among successive impacts.

Table 1.
Anthropometric Measurement of Older Chinese Women (M ± SD)

	Group XS (n = 19)	Group S (n = 20)	Group M (n = 17)	Group L (n = 5)	Group XL (n = 7)	Total (n = 68)
Waist circumference	76.0 (2.2)	83.0 (2.0)	89.5 (2.2)	97.4 (2.3)	104.6 (3.1)	85.9 (9.2)
Hip circumference	88.8 (4.5)	91.9 (4.9)	96.4 (7.0)	103.6 (9.8)	109.1 (6.7)	94.8 (8.6)
First round circumference	45.9 (3.9)	46.6 (4.6)	50.0 (5.8)	53.8 (4.5)	56.3 (5.8)	48.8 (5.8)
Vertical distance between waist and first round	28.2 (2.4)	28.2 (2.5)	28.2 (3.1)	27.0 (2.7)	29.0 (4.4)	28.1 (2.8)
Vertical distance between waist and hip	19.5 (3.4)	17.5 (3.5)	17.8 (3.0)	16.8 (1.3)	17.4 (5.4)	18.1 (3.5)
Vertical distance between waist and greater trochanter	16.5 (1.7)	16.2 (2.5)	16.7 (2.8)	15.4 (3.2)	16.1 (3.0)	16.3 (2.4)
Height	149.0 (5.6)	150.0 (5.6)	156.2 (8.4)	157.0 (11.1)	151.0 (7.9)	151.7 (7.6)

All measurements are in centimeters. XS = extra small; S = small; M = medium; L = large; XL = extra large.

Calculation and Statistical Method

Means and standard deviations were used to present the anthropometric data. The range of waist sizes was also obtained and divided into five equal portions to design five sizes, ranging from extra small to extra large. Mean measurements of the subjects in each of the sizes were calculated to develop the pants size. Independent Student's t test (two-tailed) was used to compare the impact force and impact time between conditions with and without the presence of the HP in the drop-weight test. Repeated-measures analysis of variance was also used to compare the force attenuation properties among successive impacts of the pads. Significance level was set at $P \leq 0.05$. All statistical tests were performed using Statistical Package for Social Science (SPSS) software (version 13.0, SPSS, Chicago, Illinois).

Results

Anthropometrics

The waist circumference of the subjects ranged from 72 to 109 cm (85.9 ± 9.2 cm). Five pants sizes were developed according to the range of waist sizes. The measurements for development of the sizes were established (Table 1). It was found that there was no significant difference on the position of the body landmark of the greater trochanter measured vertically from the waist among the various size groups (P = 0.869), although there was 5-cm variation (14–19 cm) among the 10th and 90th percentiles (waist circumference) of the subjects.

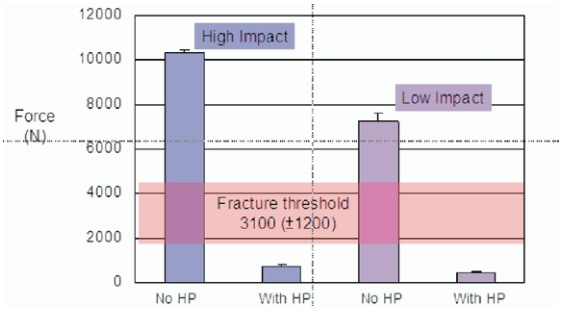

Figure 3. Force attenuation properties of the hip protector pads.

Mechanical Test

The mean impact force produced by the model was 7164 N (95% confidence interval [CI]: 7066–7262 N) and 10315 N (95% CI: 10,295–10,371 N) for low- and high-impact conditions, respectively.

The pads attenuated the impact force to 467.0 ± 42.7 N under the low-impact condition and 703.0 ± 88.2 N under high impact condition (Figure 3). Both values were significantly lower than the impact forces without the HP under the same impact condition ($P < 0.001$ for both). The mean impact forces among the successive impacts on the same sample ranged from 454 to 467 N for the low-impact condition and from 690 to 741 N for

high-impact condition. There was no significant difference in the force attenuation property of the pad across the successive impacts (low impact: $P = 0.41$, high impact: $P = 0.42$).

Under the low-impact condition, impact duration increased from 2.2 ± 0.48 ms to 25.8 ± 1.64 ms in the presence of the pad ($P < 0.001$). The pad also increased impact duration from 2.2 ± 0.48 ms to 24 ± 4.24 ms under the high-impact condition ($P < 0.001$). There was no significant difference among the impact times across the successive impacts under both impact conditions (low impact: $P = 0.14$; high impact: $P = 0.22$).

Discussion

This report describes the development of a modified HP for older Chinese women who are at high risk of fall and hip fracture. To our knowledge, this is the first study investigating the suitability of various types of fabrics and applying anthropometric data to design HP pants for older Chinese women. The HP was modified with a smaller pad size to reduce weight and bulkiness and the addition of silicon to improve comfort, yet its force attenuation properties were maintained. Future clinical study on the efficacy of improved HPs in Chinese is needed.

This study provides the first set of anthropometric data for designing HPs for elderly Chinese. In comparison with previous anthropometric studies on Caucasian subjects,[28,29] our findings show that elderly Chinese are about 8% shorter in height, 12% smaller in waist size, and 10% larger in waist-to-hip ratio. These anthropometric differences will seriously affect the fit of the pants if an HP designed for Caucasians is used for elderly Chinese. Unlike other undergarments, pants developed for holding the pads of an HP must fit tightly to hold the pads in place.[30] In addition to its effect on the function of the pants, appropriate fit also has a negative effect on patient acceptance and compliance.[15,30] This study also provides important anthropometric data regarding the location of the greater trochanter in relation to the waist in elderly Chinese. For an HP to be effective, the pads must cover the region beyond the greater trochanter because this is the most superficial and weakest part of the femur where most hip fractures occur.[31] Because the HPs were not tailored to individual users, these data are important to provide the correct location of the pockets in which the pads are held.

The pad of our HP was proved to be mechanically sufficient to attenuate the impact force under a simulated fall condition to a level that is about 2 standard deviations below the fracture threshold of the proximal femur of older women (3100 ± 1200N).[32] Thus this HP pad, despite its smaller size compared with previous foreign designs, is biomechanically able to protect the hip from fracture in most cases in a typical low-energy-impact fall. This study used a more conservative testing approach because simulation on the soft tissues covering the greater trochanter and the pelvic system was removed; this could attenuate up to 15% of the impact force.[18] Therefore, in the real-life situation, with the attenuation of the pelvic system and the soft tissue that covers the greater trochanter, the amount of force directly applied to the proximal femur after the attenuation of the HP would be even further below its fracture threshold. This HP was also proved to be effective in attenuating the impact force of successive impacts. This property is important for the HP to provide protection in repeated falls.

The pad of this HP is 20%–50% smaller and up to 40% thinner than existing designs developed for Caucasians.[18,27,33] This is because the body size of Chinese is smaller than that of the Caucasians,[22] and a smaller pad size may achieve better patient acceptance and compliance.[13] Because the pad is smaller, its positioning must be more precise. Anthropometric data are essential to locate the pocket to hold the pads precisely, and the fabric must be able to resist shrinkage due to laundering to keep the pads in place. Although the pad was smaller, its force attenuation property, which was found to attenuate 93% of the impact force, is still comparable to other designs with reported force attenuation ranging from 80% to 95%.[18,27,33] Silicon and semiflexible plastic were used in our design, compared with the hard plastic and foam that are often used in other designs.[18,27,33] This may account for the difference in force attenuation properties. The force attenuation mechanism of our HP was shown by increasing the impact time, which is inversely proportional to the force of impact. Silicon has been shown to have greater force attenuation property than foams,[34] which increases the impact duration and ab-

sorbs part of the impact energy. The semiflexible plastic also plays an important role in attenuating the force of impact. In addition to diverting the force of impact away from the greater trochanter,[18] flexing of the semiflexible shield may also occur when the weight hits the plastic,[27] increasing the impact time to attenuate the force further.

In conclusion, a modified HP with smaller pad size and sufficient force attenuation properties was successfully developed for Chinese older women. Anthropometric data were also established to identify the location of the pockets to hold the pads and design appropriately sized pants for older Chinese women. Fabric with better functionality and that was suitable for subtropical areas such as Hong Kong was also identified. The findings from this study ensure that this HP may prevent hip fractures in most falls and address the important issue of patient compliance. These issues are important to improve the effectiveness of HPs. Further clinical study is necessary to evaluate the compliance and efficacy of HPs in the elderly.

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